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Probabilistic Assessment of a Criticality in a Waste Container at SRS

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INTRODUCTION

Transuranic solid waste that has been generated as a result of the production of nuclear material for the United States defense program at the Savannah River Site (SRS) has been stored in more than 30,000 55-gallon drums and various size carbon steel boxes since 1953. Nearly two thirds of those containers have been processed and shipped to the Waste Isolation Pilot Plant. Among the containers assayed so far, the results indicate several drums with fissile inventories significantly higher (600 – 1000 grams ²³⁹Pu) than their original assigned values. While part of this discrepancy can be attributed to the past limited assay capabilities, human errors are believed to be the primary contributor.

This paper summarizes an assessment of the probability of occurrence of a criticality accident during handling of the remaining transuranic waste containers at SRS.

DISCUSSION AND RESULTS

Historically, plutonium was a valuable commodity and the goal was to minimize the amount sent to waste. In addition to the financial incentive to minimize plutonium waste, programs such as nuclear material accountability, ALARA, and the criticality safety program at the generator facilities helped to prevent excessive amounts of fissile material in waste. Much of the recent criticality safety analyses have focused on a period of time when acceptance criteria and assay systems have improved, post 1985. Prior to 1985, programs were different and the assay capabilities were limited. Since their utilization, the newer assay systems have identified some drums with higher fissile mass than their original assay values. Human errors are thought to be the primary contributor in generating waste containers with high fissile mass content.

Conservative subcritical mass limits were determined to preclude an accidental criticality during generation and storage of waste containers. Furthermore, criticality safety margins were included in operating procedures at the generator facilities to ensure the subcritical mass limits were not violated. Subcritical mass limits were established based on a maximum subcritical mass where other parameters such as moderation, fissile material

concentration, configuration, and neutron absorber content were at their optimum conditions for reactivity. Such analyses were considered deterministic in that the optimum event conditions were assumed to be present without any consideration for the probability of occurrence of such events.

This probabilistic assessment methodology, in contrast, is based on the probability of the occurrence of such conditions estimated accounting for historical data, waste packaging practices, and radiography of waste container contents.

The waste containers have been exposed to various configurations and conditions since being packaged, including interaction with other fissile material and reflection from drums, forklifts, personnel, etc. Some waste drums were buried underground and some were exposed to rain water during storage. The containers have remained subcritical because not all the conditions, such as moderation, fissile material concentration, configuration, and neutron absorber content, are in the ranges required to support a critical configuration.

A criticality involving waste containers can occur only if several independent events involving sufficient fissile mass, sufficient moderation, optimum concentration and configuration occur simultaneously. The probability of the criticality is determined by estimating the individual event probabilities. It is considered much more likely for a criticality to occur in a single high fissile content container than due to interaction among two or more high fissile content containers due to the improbability of adjacent containers having large fissile inventories. As such, this study focuses on the probability of a criticality in a container, which is given by:

$$P_{crit} = \int_L^U P(E|m) f(m) dm \quad (1)$$

where $P(E|m)$ is the probability of criticality due to event probabilities in a range to support a criticality for a system with a fissile mass m ; $f(m)$ is the probability density function for fissile mass, and $f(m)dm$ is the probability of a container having a fissile mass between m and $m + dm$.

The integral limits range from the minimum critical mass to the maximum credible fissile mass. The minimum integral limit chosen for this assessment is one kilogram of ^{239}Pu . Although a criticality is possible with a lower fissile mass, the probabilities of the events necessary for the criticality are so low that inclusion in equation 1 is insignificant. It is noted that the probability of a criticality is not very sensitive to the upper fissile mass limit because of the rapid decrease in the probability of having a container with a large fissile mass. A credible but unlikely upper mass limit was assumed to be three kilograms ^{239}Pu .

The probability of having a drum with a specific fissile mass was estimated using the assay results of 500 drums whose originally assigned inventory values were suspect. These drums came from a period in the 1980s in which human errors are believed to be a major contributor in generating waste drums with high fissile mass content. The probability for having a particular fissile mass in a drum was determined using a log-normal distribution described by the probability density function (pdf) presented in equation 2 [1].

$$pdf = \frac{1}{x\sigma\sqrt{2\pi}} e^{-0.5\left(\frac{x-\mu}{\sigma}\right)^2} \quad (2)$$

where x is the natural logarithm of the fissile mass, μ is the mean of the natural logarithm of the fissile mass values, and σ is the standard deviation of the natural logarithm of the fissile mass values for the 500 suspect drums. The cumulative distribution function (cdf) is then obtained by integrating equation 2 over the limits of the mass interval.

From the assayed drum data, the probability of a drum containing a specific fissile mass was obtained by dividing the number of drums in a mass interval by the total number of drums assayed. For the log-normal distribution, the probability for having a drum containing a specific fissile mass was obtained from the difference of the values of the cdf as shown in equation 3.

$$\text{Probability} = cdf|_U - cdf|_L \quad (3)$$

where U and L are the upper and lower mass limits, respectively, of the fissile mass interval. The fissile mass probabilities are compared in Figure 1.

The probability for enough moderator in a drum to support a criticality was estimated based on the radiography of the 500 suspect drums contents. The probability for optimum fissile material concentration was estimated based on the required height of a critical fissile pancake at the bottom of a drum divided by the total

height of the drum. The probability for sufficiently low leakage geometry was estimated as a function of fissile mass in the drum. A larger fissile mass provides more source neutrons to compensate for a higher neutron leakage geometry. The probability of the neutron absorber content was estimated based on the historical operational data and waste packaging practices.

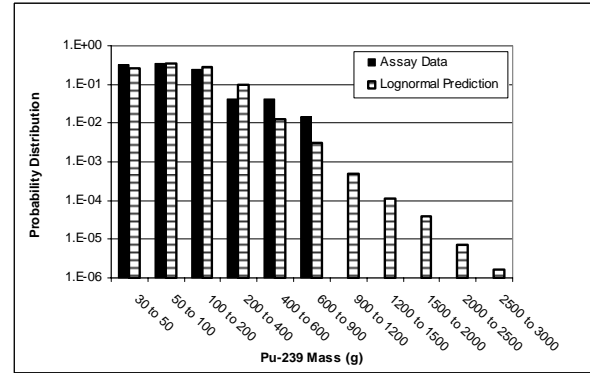


Figure 1. Comparison of Assay Results with Log-Normal Distribution Predictions

The probability of a criticality in a drum having between 1 and 3 kg plutonium is the product of event probabilities and the fissile mass probability. Equation 1 may be integrated using the trapezoidal rule to estimate the probability of criticality. The conditional probability term, $P(E|m)$, is the average of the product of the event probabilities at the end points of the mass intervals.

CONCLUSION

The probabilistic assessment study concluded that the probability of a criticality in a drum at the SRS solid waste management facility is acceptably low.

REFERENCES

1. R. O. Gilbert, "Statistical Methods for Environmental Pollution Monitoring," Van Nostrand Reinhold, New York, 1987.